Methyl bromide alternatives

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USDA

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Inside This Issue

Administration Extends Deadline on Methyl Bromide Ban to 2005

Congress has extended the proposed ban on methyl bromide to 2005, with interim phaseouts. Introduced by Congressman Vic Fazio, the new legislation was proposed as an amendment to the fiscal year 1999 appropriations bill. According to Ken Vick, USDA coordinator for methyl bromide, the new regulations will delay the ban on methyl bromide for 4 years until 2005 instead of 2001, as had been previously mandated under the U.S. Clean Air Act.

"Basically, the new guidelines ensure that regulations governing use, production, import, or export of methyl bromide in the United States be no more stringent or restrictive than those required by the Montreal Protocol," Vick said.

Under the new amendment to the Clean Air Act, in 1999, U.S. methyl bromide production and importation will be reduced from 1991 levels by 25 percent. There will be additional reductions of 25 percent and 20 percent in 2001 and 2003, respectively. The legislation exempts preshipment and quarantine uses for sanitation and food protection uses. It also allows the production, importation, and use of methyl bromide for critical uses and use by developing countries prior to their 2015 phaseout.

So, U.S. growers will have access to methyl bromide until 2005, but smaller amounts will be available. Since the chemical will be in scarce supply, the law of supply and demand will inevitably raise the price, Vick said.

Great Britain: Calculating the Loss of Methyl Bromide for Nonsoil Uses

"Some small companies could go out of business," reported Robert W. Taylor. "Methyl bromide is extremely important to some businesses in the United Kingdom, and its ban will create problems in our economy. An accelerated program, which is currently being considered by the European Union, with a phaseout in 2001, could cause considerable trade disruption."

Taylor is an insect control specialist with the Natural Resources Institute in Chatham, Kent, United Kingdom. He spoke at the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions in Orlando, Florida, December 7–9, 1998. His research was funded by the UK Department of the Environment, Transport, and the Regions, and the Ministry of Agriculture, Fisheries, and Food.

According to Taylor, 40 percent of the 1.12 million pounds (approximately

This newsletter provides information on research for methyl bromide alternatives from USDA, universities, and industry.

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500 tons) of methyl bromide used for fumigation in Great Britain goes for nonsoil uses. “Fumigation of flour mills accounts for about 38 percent of our methyl bromide use, followed by use on commodity imports, preshipment exports, buildings, and ships. We also use it on quarantine imports such as timber and plant cuttings, on aircraft, and for other unspecified uses,” he said.

Taylor and economist colleagues did a cost compliance study of what effect the loss of methyl bromide would have on these industries. They surveyed 30 pest control companies (21 responded), food manufacturers, millers, commodity importers and exporters, government agencies, shipping agencies, museums, and airlines. Telephone and fax were the primary means of gathering data, but personal visits and mail were also used.

“This survey produced some interesting results,” Taylor said. “Our larger milling organizations and food manufacturers have already reduced the use of methyl bromide. Improved sanitation practices and localized pest control are the primary alternatives for mills and structures.”

Sourcing of noninfested commodities from producer countries is being targeted by larger companies. Phosphine use is being extended but its use is constrained by low winter temperatures and a much longer exposure period. However, no alternative fumigants are yet registered.

Taylor noted that the flour mills in Great Britain vary greatly in age and design and in their capability to phase out methyl bromide quickly. Cost of switching to something other than this chemical depends primarily on whether heat is likely to be used, either alone or as part of a combination treatment.

For imported commodities—such as cocoa, coffee, rice, dried fruits, and nuts—principal problems are ineffective fumigation and commodity management practices in producer countries. Often, refumigation of a high proportion of these commodities, particularly cocoa, is necessary on their arrival in the UK. Better commodity management practices in producer countries and improved fumigations with phosphine could greatly reduce this need to refumigate, Taylor said.

“Loss of methyl bromide as a fumigant could also result in loss of some of our export markets,” he said. “Some of our commodities are exported to Australia and New Zealand where methyl bromide is specified. Plant cuttings that we export require a phytosanitary certificate to show that they have been treated with methyl bromide. And, we fumigate used clothing that is primarily exported to Africa.”

With the loss of methyl bromide, major pest control servicing companies that have not yet done so will likely diversify activities. The effect of the phaseout will depend on how dependent they are on methyl bromide.

“But diversification will likely be more difficult for small pest control companies that rely exclusively on methyl bromide. Several of these companies indicated in our survey that their business will cease once methyl bromide is no longer available,” Taylor reported. “Small commercial companies that import chrysanthemum cuttings expect to go out of business. Exporters of new plant varieties expect that business will be halted with some countries when methyl bromide is no longer available.”

Transferring Technology of Methyl Bromide Alternatives From Lab to Field

“For California strawberry growers to use methyl bromide alternatives, they must overcome or adopt many cultural, economic, political, regulatory, and training issues,” said Christopher Winterbottom. “For growers, the bottom line is profit, and an unproven alternative poses a risk that is hard to take without assurance of success.”

Winterbottom, who is with the California Strawberry Commission in Watsonville, discussed technology transfer of methyl bromide alternatives at the 1998 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. It was held in Orlando, Florida, December 7–9, 1998.

“Effective research should eventually produce a product,” Winterbottom stated. “However, right now much of the research on methyl bromide alternatives is still in the basic, or demonstration, stage. This means that the research is not yet ready to be turned into proven practices or products that form or fit into a cropping system.”

He said that the process of transferring information from the lab to the grower is done in five stages: technology discovery or innovation, development and evaluation, demonstration and confirmation, communication and marketing, and adoption.

Discovery

Scientists from private firms, the University of California, and USDA are searching for alternatives to methyl bromide. The private firms include agrochemical companies like pesticide application firms, contract research firms, large strawberry operations with research personnel, and many others. This is the brainstorming stage.

Development and Evaluation

After the ideas are born, they must be expanded for further action. The core group is investigating preplant soil fumigants and application methods,

biocontrol agents, crop rotation practices, and soil amendments on small plots at test stations. They're also testing potential alternatives in a limited number of small, on-farm field trials.

"It's at this stage that economics come into play," said Winterbottom. "Some of the economics must be figured out before we even get a potential alternative to the demonstration field. If we come up with something that works, we must also consider whether or not it would be a viable product for growers to use."

For example, he said that while crop rotation with strawberries might be helpful in some instances, there is no market mechanism to do so. Or, a company could screen 500 pesticides and get perhaps one that might be potentially viable. Would this pesticide really be used by the farmer? What about registration—is it feasible?

Demonstration and Confirmation

Researchers seek cooperative growers to test their potential alternatives, Winterbottom said. The success of a particular alternative often depends on many variables such as a grower's level of skill. For instance, one grower may manage operations differently or more efficiently than another, or have a different level of skill in working with equipment. There can also be significant differences in the level of capital that growers have available. All of these factors affect the way growers treat a prospective alternative to methyl bromide.

"A viable alternative must work for most growers, not just a select few," Winterbottom explained. "So because of these variables, there is not one alternative to methyl bromide. Growers must mix and match, according to their own abilities, capabilities, and circumstances, such as trying host resistance plus chemicals plus biocontrol to form a cohesive, functional cropping system."

And the potential alternatives must be tried on the farm. In the 1993–94 growing season at Watsonville, University of California's John Duniway set up an on-farm trial using the most promising methyl bromide alternatives. He repeated the trial during the 1994–95 season.

Because of the high cost and logistics connected with growing strawberries statewide, testing potential alternatives must be a collaborative effort. Therefore, USDA's Agricultural Research Service provided some funds and the California Strawberry Commission, along with Tri-Cal, in Hollister, California, and interested farmers, set up five on-farm trials to demonstrate the effectiveness of potential alternatives.

"We conducted trials in four of California's strawberry production regions, beginning with the 1996–97 growing season," Winterbottom reported. "The test plots were large, about half an acre or more, and were fumigated with the most promising methyl bromide alternatives available."

Then in the 1997–98 growing season, they established nine on-farm demonstration trials, with at least one in each production region.

"We have set up eight field trials in the 1998–99 growing season," said Winterbottom. "They will demonstrate the performance of the best-available methyl bromide alternatives to the grower. This exercise will help us identify problems that could arise when the alternative is used on a larger scale and exposed to actual strawberry farming conditions such as various soils, microclimates, pest and disease pressures, and varying farming abilities."

Communication and Marketing

Winterbottom said that transferring the technology in order to implement alternatives to methyl bromide is like a jigsaw puzzle, with all of the aforementioned pieces fitting together to make a complete picture. "And, they're all intricately interwoven. One of the most important pieces of that puzzle is communicating information about the alternatives to growers."

The California Strawberry Commission (CSC) regularly publishes information on alternatives in a newsletter called the *Pink Sheet*, which is distributed to Commission members. CSC also holds farmer workshops and field days in each of the strawberry production districts and encourages direct contact between the grower and CSC-funded scientists who are doing research on strawberries.

Scientists from CSC, the University of California, and the Agricultural Research Service present their research results at professional meetings and publish them in scientific journals. ARS also publishes this newsletter, the quarterly *Methyl Bromide Alternatives*, which can be obtained in hard copy and from the Internet at **http://www.ars.usda.gov/is/np/mba/mebrhp.htm**. This newsletter is written for a nonscientific audience and covers national and international news from all aspects of the methyl bromide issue. Its purpose is to report research progress on finding alternatives to methyl bromide and to serve as a link between researchers and agricultural producers, marketers, and consumers.

Adoption

Winterbottom said that the bottom line is viability and profitability. Growers need something that is effective against strawberry pests, is consistent, and will work now. "Growers don't have the time or the money to figure out variables in the field. They need something that has been tried and tested to reduce their risk."

He said that growers' rate of adoption of an alternative or a set of technolo-

gies will depend on the following characteristics:

- Relative advantage—how is it superior to others?
- Compatibility—how does it fit or work within the current cropping system?
- Complexity—how difficult is it to understand and use?
- Divisibility—can it be tried on a limited basis?
- Communicability—are its results readily apparent and easily described to others?

Divisibility is being addressed through current on-farm trials and the results are being communicated to the scientific community and to other growers. The first three characteristics need to be understood, for each alternative, on a field-by-field basis before the grower decides which alternative to adopt for a given field.

"To date, no methyl bromide alternative has been adopted on a large scale for strawberry production in California," Winterbottom reported. "There are a number of methyl bromide alternatives, but no replacements."

Managing Pests With Good Manufacturing Practices

"Redefining pest management responsibilities to include input into sanitation, maintenance, and even production is not as absurd as it may seem," said Dean M. Stanbridge. "We instituted such a management program at several facilities, both large and small, achieving a success rate ranging from 60 percent to a total elimination of methyl bromide for 5 years."

Stanbridge gave his report at the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions in Orlando, Florida, December 7–9, 1998. He is vice president of operations, Professional Pest Consultants, Inc., Ontario, Canada.

Instead of a reactive approach to eradicate pests, Stanbridge advocates a proactive stance. Proactive controls are considered expensive and risky. Because of this, they're not widely used. Also, its much easier to eliminate pests with fumigants. However, the fumigant that is primarily used to disinfest structures is methyl bromide. And the use of methyl bromide is being gradually phased out over the next few years, with a complete ban in 2005.

"Understanding a pest's biology is the first step in controlling it," he reported. "Therefore, we must identify the pests we're dealing with."

Case in point: Stanbridge was approached by a baked goods processing facility that wanted to eliminate their use of methyl bromide because they knew it had been declared an ozone depletor and would eventually be banned.

Stored-product pests in this facility included confused flour beetles, black carpet beetles and Indianmeal moths. German cockroaches and house mice were secondary pests.

"We decided to first identify areas in the facility that would support the biology of these pests, then aggressively attack those areas. To gain immediate control, we concentrated on better sanitation and reducing the number of places the pests could thrive," Stanbridge reported. "Once control was complete, we developed maintenance plans to keep pests eradicated."

Making changes to food plants can be very complex. "We knew that our success with eradicating these pests without pesticides would depend on help from the plant mangers," Stanbridge said. "Therefore, we included not only the plant manager, but managers of maintenance, sanitation, quality assurance, pest control, and production. And we worked as a team."

It was vital to get these people involved because the maintenance manager would be responsible for equipment that might need to be modified to eliminate places the pests could reside. This person was also involved in anything pertaining to the structural aspects of the facility and in instituting any changes that might be recommended.

Cleaning recommendations would be implemented by the sanitation manager, who also identifies and cleans areas and equipment that may harbor insects.

The production manager would allow the time required for good manufacturing practices, and the plant manager carried through on any recommendations and reviewed requests for equipment and structural changes.

"It's fairly easy to incorporate pest management principles because some degree of good manufacturing practices already exists in most food-processing facilities," Stanbridge pointed out. "But identifying critical areas where pests persist isn't easy because it isn't static. It is ever changing."

Part of the baking facility was built 100 years ago, and 20-year-old steel beams support the newer packaging and warehouse areas. There were no walls to separate many areas, making the job of pest control even more difficult.

"Because of the plant's age, we knew that structural changes would be very expensive. But what we suggested had several benefits, which justified the money spent to implement our plans," Stanbridge said.

Stanbridge's team suggested that the plant install a wall between the flour silo/sifting and mixing. This would not only reduce airborne flour's settling on high surfaces, but it would also reduce insect food and breeding

sources. And, it would reduce the number of times these areas needed to be cleaned, resulting in a savings for maintenance. Fewer cleaning times meant less disruption to production. Food product safety would be enhanced since no insects or old flour would be falling from high surfaces.

Suggestions for equipment were primarily to locate and eliminate areas that might harbor insects. For example, the team found that a certain piece of equipment simply needed to be turned over to keep flour from accumulating. This accumulation was drawing insects and providing breeding sources. Here again, food safety was enhanced and the need for constant cleaning was reduced, saving maintenance costs and production time.

"We found that the most difficult factor lay in changing employees' habits," Stanbridge said. "Although the least expensive to implement, these changes take the longest time to effect." Staff training will be required in many cases.

Implementing good manufacturing practices may need to be supplemented by some pesticide applications, Stanbridge said, but these should be kept at a minimum.

Three months after suggestions were presented to the owners of the baking facility, the management team saw changes being made. And the full plan of instituting good manufacturing practices was implemented in 6 months.

"That was 5 years ago and the baking facility has not used methyl bromide since," Stanbridge reported. "The key here is time. It takes time to turn time-honored practices around. We can't wait until methyl bromide is banned and then start. We must start now."

EPA Updates the Environmental Impact of Methyl Bromide

Because science has fingered methyl bromide as a culprit in destroying the ozone, regulatory actions were needed to control emissions. "Although regulatory action can be difficult and confusing initially, it can lead to a better way of doing things," said Bill Thomas, an entomologist with the U.S. Environmental Protection Agency. EPA's Stratospheric Protection Division presented a poster update on the environmental impact of methyl bromide at the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, held December 7–9, 1998, in Orlando, Florida.

Under the Clean Air Act, methyl bromide had been scheduled for phaseout in the United States on January 1, 2001. However, Congress recently signed legislation to extend the use of this pesticide and gradually phase it out by 2005.

Worldwide, most of the methyl bromide used goes to fumigate soil for preplant purposes. Thomas said that the breakdown is 70 percent to fumigate soil, 16 and 8 percent to fumigate durable and perishable commodities, respectively, and 6 percent to treat structures.

"Of all the methyl bromide used, North America uses the most, at 43 percent of the total. Asia uses 24 percent and Europe, 24 percent, while the remaining 9 percent is used by Africa, South America, and Australia," Thomas reported.

In the United States, growers use 43 million pounds of methyl bromide each year. Of that, about 35 million pounds go for soil fumigation, 5 million for postharvest uses, and 3 million for structural fumigation.

This means that 81 percent of the chemical used goes to prepare the soil for vegetables, orchards, nurseries, and other crops. Of this total, 62 percent is used for vegetables; 10 percent, orchards; 15 percent, nurseries; and 13 percent, other crops.

Postharvest uses account for 12 percent of the total U.S. methyl bromide use. Of this, 57 and 34 percent are used on perishable and durable commodities, while 9 percent is for quarantine use.

"Because most of the methyl bromide used is for soil fumigation, it is inevitable that much of it escapes into the atmosphere," Thomas said. "We estimate that about 50 to 90 percent of the chemical used in the soil will escape into the air. From 80 to 100 percent of that used to fumigate commodities will escape."

Once in the stratosphere, high energy radiation releases a very reactive bromine atom that destroys ozone molecules, he said. "In fact, one atom of bromine is 50 times more destructive to ozone than one atom of chlorine."

According to atmospheric scientists, destroying stratospheric ozone molecules causes the ozone layer to thin, resulting in more ultraviolet light reaching the earth's surface. This increases surface radiation, which is harmful to biological organisms, including plants and humans.

Therefore, since atmospheric scientists agreed that methyl bromide has an ozone depletion potential of 0.4, it was classified as a significant ozone depletor.

"Any substance with an ozone-depleting potential (ODP) of 0.2 or higher must be phased out within 7 years, under Title VI of the Clean Air Act," Thomas reported. "In 1993, methyl bromide's ODP was 0.7. On this basis, EPA was authorized in December 1993 to phase out use in 2001 and freeze production and importation at 1991 levels."

But in November 1998, Congress changed these regulations to be more in line with the Montreal Protocol. The new legislation mandates that methyl bromide produced and imported will be reduced as follows:

- 25 percent in 1999,
- 50 percent in 2001,
- 70 percent in 2003,
- 100 percent in 2005.

Preshipment and quarantine use are exempt from this mandate, and critical agricultural uses will be allocated after 2005.

Like others involved in this issue, Thomas said that there is not likely to be a single, magic bullet alternative to methyl bromide. An integrated approach to pest control will be necessary by carefully considering the crop or commodity, climate, type of soil, and probably most important, the target pest.

Alternatives proposed for soil fumigation are dependent on many factors, including the pest, crop, geographic location, time of year, and soil type. Chemicals proposed as alternatives include 1,3 dichloropropene, chloropicrin, and methyl isothiocyanate (MITC) generators such as metam sodium or dazomet. Nonchemical methods include crop rotation, organic matter, steam, solarization, and ozone.

"Proposed alternatives for commodity and structural treatment are also dependent on a wide range of factors: the commodity, the pest, storage or shipping method and the time of year, and trade requirements," he noted. "Chemicals suggested are phosphine and sulfuryl fluoride. Nonchemical treatments are irradiation, nitrogen, carbon dioxide, and cold and heat."

Although no single treatment has yet surfaced that can replace methyl bromide, Thomas said that "alternatives do exist and will ultimately replace methyl bromide."

Technical Reports

Methyl Iodide: Recent Field Results

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So far, methyl iodide is the only single chemical alternative to methyl bromide that has been shown to be effective. To quickly review, methyl iodide is chemically analogous to methyl bromide. Thus, it is expected to have very similar biological effects. Methyl iodide is not a threat to the ozone layer since it decomposes rapidly in sunlight. As it is a low boiling liquid, it is safer to handle and measure. For laboratory purposes, it is almost exclusively used over the more-difficult-to-handle methyl bromide which is a gas at normal temperature and pressure.

In recent published work we have shown that methyl iodide was more effective than methyl bromide in halting weed seed germination and that it was effective at lower temperatures.

The purpose of this technical report is to announce some preliminary results with methyl iodide in field tests.

Peach Replant

Peach replant syndrome is an ill-defined disease complex which causes stunting of newly planted peach seedlings on old orchard land. Currently, in such a situation the soil is fumigated with methyl bromide at a rate of 300–400 lbs./acre before the seedlings are planted. This treatment ensures that the trees will reach maturity faster and be heathier. We have begun field trials in a peach replant situation comparing methyl iodide and methyl bromide fumigations on USDA/ARS land in Parlier, CA.

We started our first trial in 1997. We fumigated prepared ground with methyl iodide and methyl bromide at 450 lbs./acre using tarp coverage for seven days after treatment. Untreated ground served as a control. Four repetitions of each treatment were randomized with four controls. After one year, the trees planted in the treated plots could easily be picked out from those in the untreated plots. The height and canopies were markedly different. The trees planted in fumigated ground were taller and had larger canopies than the trees planted in the untreated control ground. Trunk diameters of the trees measured in 1998 provided quantitative measure of the visual observations. The average diameter of trees in the respective plots were: control, 20.2 cm, methyl iodide, 32.6 and methyl bromide, 30.4. There was no significant difference between the treated trees and both were significantly different from the untreated controls.

A second trial begun in 1998 is showing similar visual and trunk diameter differences after the first growing season. Therefore, based on this data, methyl iodide and methyl bromide appear equally effective in avoiding the peach replant syndrome.

Vine Decline of Muskmelon

First year results from the comparison of methyl iodide and methyl bromide fumigation of field sites naturally infested with *Monosporascus cannonballus*, the causal agent of vine decline, have been encouraging. The Desert Research and Education Center of the University of California in the Imperial Valley near Holtville was the site of the studies. We studied two cropping seasons with preplant fumigation only before the first (spring) season; the second season (fall) crop was replanted with no further fumigation. Because there

were several different materials being tested in this study, the entire area was subjected to preplant treatment with Telone for nematode control prior to the spring seeding.

In the spring, we applied methyl bromide and methyl iodide at 400 lbs./acre, preplant—through irrigation drip tape under plastic mulch—as hot gasses, using an application system of our design. The treatments were replicated and we included untreated controls in the experiments.

At weekly intervals after planting, we extracted plants from the soil and rated them for evidence of infection. The condition of both the canopy and roots was rated on a scale of 0–4, where 0 = heathy, 1 = 25 percent, 2 = 50 percent, 3 = 75 percent and 4 = 100 percent, collapsed or infected, respectively. For the Spring crop, the root ratings at harvest were: control = 2.9, methyl bromide = 2.0 and methyl iodide = 1.1. The canopy ratings were: control = 2.9, methyl bromide = 1.1 and methyl iodide = 0.9. Both treatments gave excellent and statistically significant control of the disease.

In the fall, we replanted treated plots to evaluate any carryover effect of the chemicals. Root ratings at harvest were: control = 3.7, methyl bromide = 2.0 and methyl iodide = 1.3. The canopy ratings were: control = 2.2, methyl bromide, 1.1 and methyl iodide = 0.3. More importantly, there was a late season collapse of the vines in all but the methyl iodide plots. In practical terms, this meant that the only crop that could have been harvested in the fall was in the methyl iodide plots. When the canopy collapses, the melons are ruined by sunburn and cannot be sold.

This work will be repeated in 1999. As far as efficacy is concerned, methyl iodide continues to be as effective, or even more effective, than methyl bromide. The next hurdle for methyl iodide will be registration.

Evaluating Methyl Bromide Alternative Fumigants on Tomato Under Polyethylene Mulch in Florida

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Our objective over the past 5 years has been to evaluate the most promising alternative multi-purpose soil fumigants. Comparisons are made against two formulations of methyl bromide (MeBr 98–2 and 67–33). The trials are conducted in fields infested with root-knot nematodes, soilborne diseases, and weeds. The test systems include tomatoes grown in drip irrigated polyethylene mulch culture. The most promising alternative soil fumigants identified to date include 1,3 dichloropropene (Telone®) combined with either chloropricin (pic) at 17 percent (C17) or 35 percent (C35), or metam sodium (Vapam®) combined with pic or 1,3–dicloropropene (1,3–D). However, to date, there has been little work on the latter combination. When either 1,3–D or metam sodium are applied singly or in combination with pic, a herbicide must be used. The only herbicide available for nutgrass suppression is pebulate (Tillam®).

In past work, metam sodium, applied as a single treatment, has not provided acceptable nematode control, whereas C17 at 35 gal./acre + 4 lb./acre of pebulate has in most cases provided good control of plant-parasitic nematodes, some soil fungal diseases, and suppressed nutsedge in polyethylene mulched tomato. Consequently, the latter treatment is currently considered the best alternative for methyl bromide. However, our biggest data gaps regarding the use of these fumigants as substitutes for MeBr are the lack of performance data in fields infested with diseases such as fusarium wilt, fusarium crown rot, bacterial wilt, and southern blight, and seedling diseases caused by *Pythium* and *Rhizoctonia*. The latter diseases will affect plant stands.

The following is a summary of some MeBr alternative trials conducted at the University of Florida, Gainesville, during the fall of 1997 and spring, 1998. We tested the alternative fumigants at two sites: the Horticultural Unit (Millhopper fine sand) and the Agronomy Unit (Arredondo fine sand). The treatments were applied with standard industry equipment. We injected the fumigants 10 inches deep with 3 chisels per bed into 3-ft-wide beds (30-ft long). MeBr 98–2 was tested at 400 lbs./acre, 67–33 at 350 lbs./acre, C17 at 35 gal./acre, C35 at 18, 24, 30, and 36 gal./acre, and metam sodium (42 percent formulation) at 75 gal./acre. Pic applied in combination with metam sodium was tested at 75, 100, and 150 lbs./acre.

We sprayed metam sodium and pebulate over the bed surface, incorporating 4 to 6 inches deep into the soil. The treatments were immediately covered with polyethylene mulch. Irrigation was applied via drip tubing before transplanting on some metam sodium plots in an effort to enhance fumigant activity. All treatments were tested in an approved statistical field design and replicated 5 to 6 times. Solar-Set and Agriset 761 tomato seedlings were transplanted for the fall and spring trials, respectively. We counted purple and yellow nutsedge seedlings that grew through the mulch on the side of the bed where the drip irrigation tubing was placed. After harvest, six tomato plants were dug, and roots were rated for the presence of root-knot nematode galling. We also made a count of plants infected by soilborne diseases, southern blight or bacterial wilt.

In the fall study (1997), marketable yields with MeBr, C35 (24 gal./acre), and metam sodium + pic were significantly higher than with the check. Yield with metam sodium alone was similar to that with the check. Additional water applied before transplanting with metam sodium did

not increase yield over treatment with metam sodium that had no additional irrigation water. Nutsedge was controlled with MeBr and all treatments with pebulate. Metam sodium alone or with pic but without pebulate did not reduce nutgrass. Nematode root-gall ratings were high on tomato grown without fumigants, low with MeBr, and intermediate with all other treatments except with the low rate of C35 (18 gal./acre).

In the 1998 spring trials, yields at the Hort Unit were highest with MeBr, C35 (30 gal./acre), and C17 (35 gal./acre) and were significantly lower in the untreated control. Yields with other treatments were not different from the untreated control. Nematode root-gall ratings were lowest in plots treated with MeBr, C35 and C17, and significantly higher with the untreated control. Root-gall ratings were significantly higher with all metam sodium treatments and were not different from the untreated control. Nutsedge control was excellent with MeBr, metam sodium + pebulate, and C17 and C35 + pebulate treatments. The addition of pic with the metam sodium + pebulate resulted in nutsedge counts that were similar to that with the check treatment.

At the Agronomy Unit, 42 percent of the plants in the untreated control plots were diseased (bacterial wilt or southern blight). In the treated plots, the number of diseased plants ranged from 0 = metam sodium + pic (75 gal. + 150 lbs./acre), and C35 (36 gal./acre) to 13 percent = metam sodium alone. Other plots were intermediate between these percentages. None of the metam sodium treatments reduced root-knot nematode galling compared with the untreated control. This is consistent with previous data. Also, the lower rate of C35 (24 gal.) did not result in a significant reduction in root galling. The remaining treatments resulted in 85 percent to 90 percent reduction in root galling. The MeBr treatments, C17 and C35 treatments (except C35 at low rate), and metam sodium + pic + pebulate increased yields compared to the untreated control.

In summary, the combinations of various rates of pic with metam sodium have given inconsistent results. In the fall study, this treatment provided fruit yields similar to that with MeBr, but in the two spring studies, the treatment combinations looked good in only one treatment. It is important to point out that neither pic, metam sodium nor combinations of the two reduced root-knot nematode galling on plants at harvest. As in past studies, C17 and C35 + pebulate have given the most consistent results when compared with MeBr. C35 was most effective at 30 to 36 gal./acre. These higher rates generally provide control of root-knot nematodes similar to that provided by MeBr.